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TEMPORAL AND SPATIAL VARIABILITIES IN SHALLOW WATER ACOUSTICS: MEASUREMENTS AND PREDICTIONS

by

Hassan B. ALI
Melchiorre C. FERLA
Tuncay AKAL

15 MARCH 1985

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tel: national 0187 540111
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Hassan B. Ali
Melchiorre Ferla
Tuncay Akal

15 March 1985

This memorandum has been prepared within the SACLANTCEN Underwater Research Division as part of Project 05.

O.F. Hastrup

O.F. HASTRUP
Division Chief

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TEMPORAL AND SPATIAL VARIABILITIES IN SHALLOW WATER ACOUSTICS: MEASUREMENTS AND PREDICTIONS

by

Hassan B. Ali, Melchiorre C. Ferla and Tuncay Akal

ABSTRACT

An acoustic signal propagating in the sea is generally degraded not only by interactions with the bottom and surface boundaries, but also by volume inhomogeneities caused by non-uniformities in temperature, density, and salinity distributions. The degradations in the acoustical signal are manifested by fluctuations in its amplitude and phase and by an accompanying loss in its coherence properties. The results of experiments conducted in a shallow water area of the Mediterranean are used to establish correlations between fluctuations in acoustic transmission loss and variability in the environmental parameters. The physical processes responsible for the observed fluctuations are identified primarily with inertial effects, semi-diurnal tides, and fine-structure. Using a modified version of SNAP (SACLANTCEN Normal Mode Acoustic Propagation Model) comparisons are made between measured and predicted acoustic transmission loss.

INTRODUCTION

In attempting to use acoustics in the ocean, one is inevitably confronted by the basic problem of the inherent complexity of the medium. The parameters controlling the propagation vary, usually unpredictably, both spatially, and, more significantly, temporally. An acoustic signal propagating in such a medium is consequently scattered not only by interactions with the bottom and surface boundaries, but also by volume inhomogeneities caused by non-uniformities in temperature, density, and salinity distributions. The degradations in the acoustical signal are manifested as fluctuations in its amplitude and phase and by an accompanying loss in its coherence properties.

Although the mechanisms leading to fluctuations in acoustic propagation are diverse, an essential common feature is an associated non-uniformity in the medium, either temporal or spatial or both. Depending on the temporal and spatial scales involved, the mechanisms can be considered either deterministic or random [1]. The general circulation of the ocean ("ocean climate") and its associated current systems (Gulf Stream, Kuroshio, etc) are characterized by horizontal scales of variability limited only by the size of the basin, vertical scales of a few 100 m, and temporal scales from a few days to seasonal. These are deterministic structures. The intermediate scales of variability, including ocean motions such as fronts and eddies, can also be considered to be deterministic perturbations from the mean structure. The associated scales of variabilities are of the order of

Smaller scales comprise internal waves, fine-structure, and microstructure. These phenomena must be considered random. The internal waves are characterized by scales from 100 m to 10 km or more in the horizontal, 1 to 100 m in the vertical, and from about 10 min to 1 day in time. Since they owe their existence to the restoring forces due to the density gradient and the Coriolis force, the frequency spectra of internal waves are bounded by the inertial frequency at the low end and by the buoyancy frequency (Brunt-Väisälä) at the high end. Variability induced by internal waves has been found to be a very significant source of sound scattering, receiving considerable attention in recent years [2,3,4]. Variability induced by fine structure and microstructure involves scales from several to hundreds of metres in the horizontal, centimetres to about 10 m in the vertical, and temporal scales of the order of milliseconds. Such variability would be expected to affect sound propagation in the frequency range from approximately 1 kHz to tens of kilohertz.

Figure 1 [1] summarizes the temporal fluctuations often observed in acoustic propagation experiments. In the measurement results to be discussed here, the dominant mechanisms appear to be low-frequency internal waves (i.e., inertial oscillations), fine-structure, and semi-diurnal tides.

1 PROPAGATION CHARACTERISTICS OF THE TEST ENVIRONMENT

In order to examine the relationship between environmental variability and temporal fluctuations in transmission loss, an acoustic propagation experiment was conducted in a shallow water region of the Mediterranean Sea (Strait of Sicily) where the water depth varied from about 40 m to 85 m, as seen in Fig. 2. Although the bathymetry of the area is fairly complex, that along the propagation run is relatively simple. The water circulation in the region can be described as a three-layer system: water of Atlantic origin enters the Mediterranean in the surface layer while more saline Levantine water flows in the opposite direction in the lower layer. A third, intermediate layer, exists in which turbulent mixing occurs. A temperature/ salinity plot of the measured data, not shown here, confirms this general behaviour.

For the experimental situation depicted in Fig. 2, broad-band (explosive) sources were dropped on a quasi-hourly basis, the signal being received at 35 km distance by a vertical array of hydrophones. Simultaneous samplings were taken of the pertinent oceanographic parameters: sound speed, temperature, salinity, and density (STDV casts). The test was conducted during summer conditions (August 1976), a typical depth profile of the environmental parameters being seen in Fig. 3. This type of profile tends to lead to downward refracted acoustic paths, resulting in greater bottom interaction than would occur for a winter profile. Vertical stratification and some fine-structure are evident in the profiles. A closer analysis of the sound speed profile over shorter intervals in depth and sound speed reveals more clearly the presence of fine-structure, characterized by vertical dimensions of the order of from centimetres to one or two metres.

The effect on acoustic propagation is shown in Fig. 4, which presents contours of measured transmission loss, in 1/3 octave bands, in the frequency/range plane. The existence of an optimum frequency range for

PERIOD	PRINCIPAL ENVIRONMENTAL PARAMETER	PRINCIPAL ACOUSTIC EFFECTS
ms	FINE AND MICROSTRUCTURE	AMPLITUDE, PHASE AND PROPAGATION PATH FLUCTUATIONS; HIGH FREQUENCY SCATTERING
5 sec	SURFACE WAVE SIGNATURES	AMPLITUDE MODULATION; SCATTERING
10 min	INTERNAL WAVE SIGNATURE	AMPLITUDE AND PHASE FLUCTUATION; SIGNIFICANT, REFRACTION OF NEARLY HORIZONTAL PATHS
4 hr	SHALLOW WATER TIDES	NOISE-LIKE AMPLITUDE FLUCTUATIONS;
12 hr	SEMIDIURNAL TIDES	PHASE FLUCTUATIONS SIMPLY CORRELATED WITH TIDAL VARIATIONS.
24 hr	DIURNAL TIDES	GREATEST EFFECTS IN SHALLOW WATER
4 day		FLUCTUATIONS IN PROPAGATION PATH, ACOUSTIC INTENSITY; DISTORTION OF SIGNAL SHAPE.
15 day	MESOSCALE PHENOMENA (EDDIES, FRONTS)	
1 month		
	OCEAN CLIMATE	FLUCTUATION IN AMPLITUDE, PHASE AND PROPAGATION PATH
1 year		

FIG. 1 TEMPORAL VARIATIONS OBSERVED IN ACOUSTIC DATA

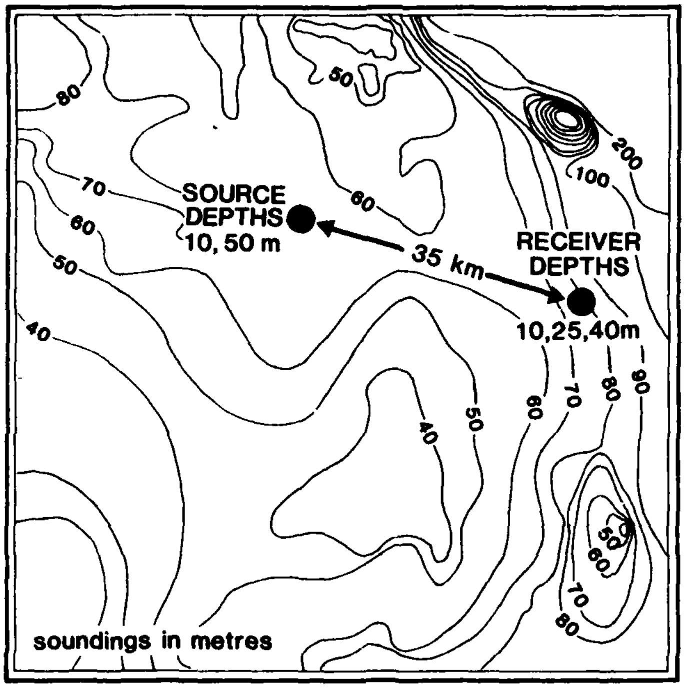

FIG. 2
ENVIRONMENT OF THE EXPERIMENT

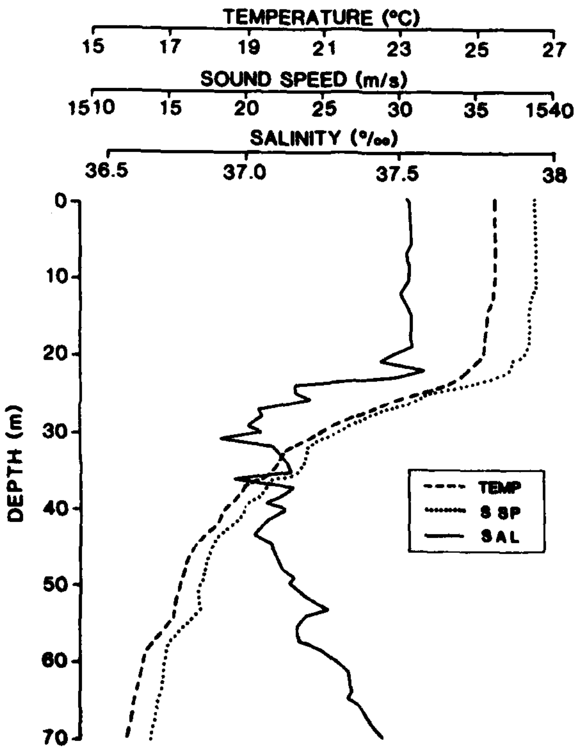

FIG. 3
AN EXAMPLE OF DEPTH PROFILES OF TEMPERATURE, SOUND SPEED, AND SALINITY

The effect on acoustic propagation is shown in Fig. 4, which presents contours of measured transmission loss, in 1/3 octave bands, in the frequency/range plane. The existence of an optimum frequency range for acoustic propagation — i.e., a range for which the transmission loss is minimal — is clearly evident and, in this case, lies between approximately 100 and 400 Hz. The explanation for this is as follows: the very low frequencies suffer large attenuation as a result of bottom interaction (penetration in the bottom increasing with increasing wavelength), whereas the very high frequencies are greatly attenuated by absorption in the water column and, possibly, by scattering from fine-structure. Hence the existence of an optimum frequency range somewhere in between the two extremes <5,6>. In other words, for the conditions typified by Fig. 3, shallow water behaves like a band-pass filter for propagating broadband acoustic signals.

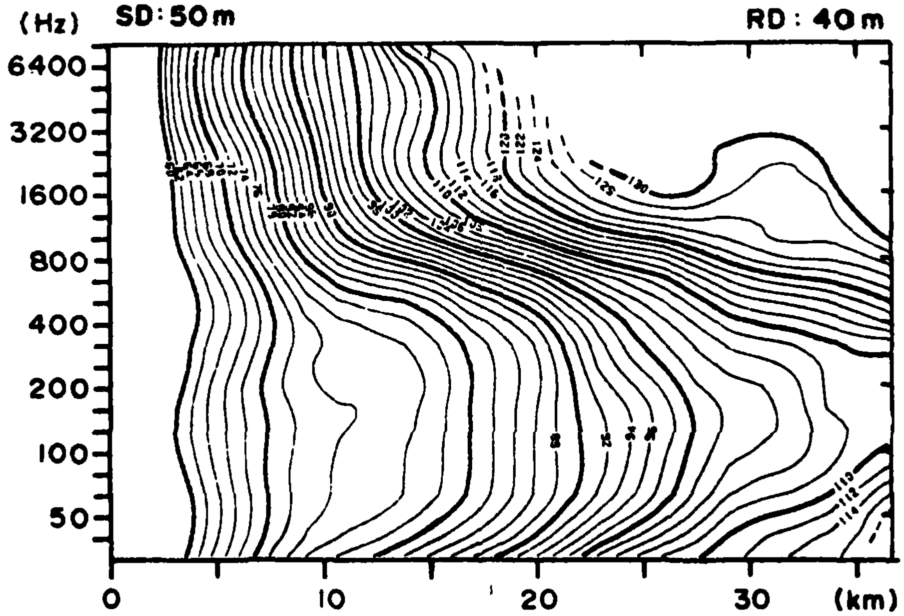

FIG. 4 CONTOURS OF MEASURED TRANSMISSION LOSS UNDER SUMMER CONDITIONS

2 TEMPORAL VARIABILITY IN THE ENVIRONMENTAL DATA

Of primary interest for our purpose is the temporal behaviour at a fixed range, here 35 km, of the relevant parameters. An example is given in Fig. 5, which shows the variation of sound speed with depth at the receiver position over a period of 25 hours.

The contour lines are spaced 2 m/s apart, a greater density of lines indicating, of course, a steeper gradient in the sound speed profile. Thus the range from approximately 25 to 35 m comprises the steepest portion of the thermocline. The region down to 20 m or so is essentially isovelocity, with sound speed approximately 1538 m/s. The fluctuations in sound speed are quite evident, particularly at a depth of 25 m or so within the thermocline. Stated differently, the contour plot clearly indicates an oscillation in the width of the mixed layer (surface duct). The frequency content of these oscillations is of particular interest, providing as it does clues to the responsible mechanisms. Examples of frequency spectra of the relevant environmental parameters, obtained from FFT's of the corresponding normalized time series, are shown in Fig. 6. The dominant fluctuations occur in the frequency range from 0.05 to 0.06 cycle/h, or for periods from 20 to 17 hours. This range does, in fact, correspond to that of inertial oscillations for this geographical area. One can only speculate as to the origin of the apparent inertial oscillations in this case, but there is some evidence, both from the literature [7] and from the present data, that they may be wind-induced. At the particular depth (25 m) investigated for Fig. 6, semi-diurnal effects seem to be insignificant. However, from the results obtained at other depths it appears that with increasing depth the inertial oscillations decrease in importance relative to the semi-diurnal effects. This is consistent with the supposition that the dominant forcing mechanism in this case is meteorological, and therefore that the effects are expected to diminish with depth.

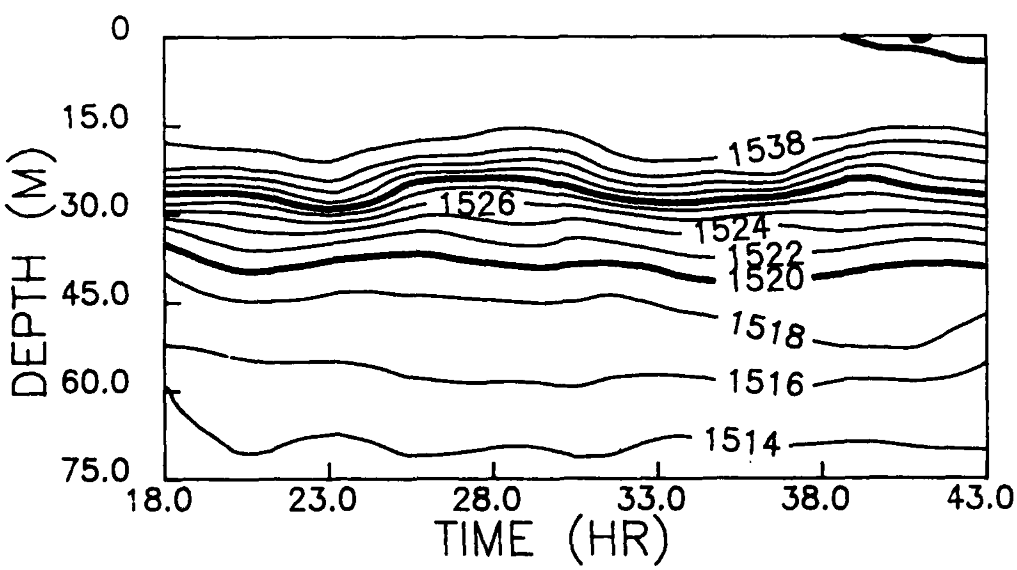

FIG. 5 TIME/DEPTH CONTOURS OF MEASURED SOUND SPEED

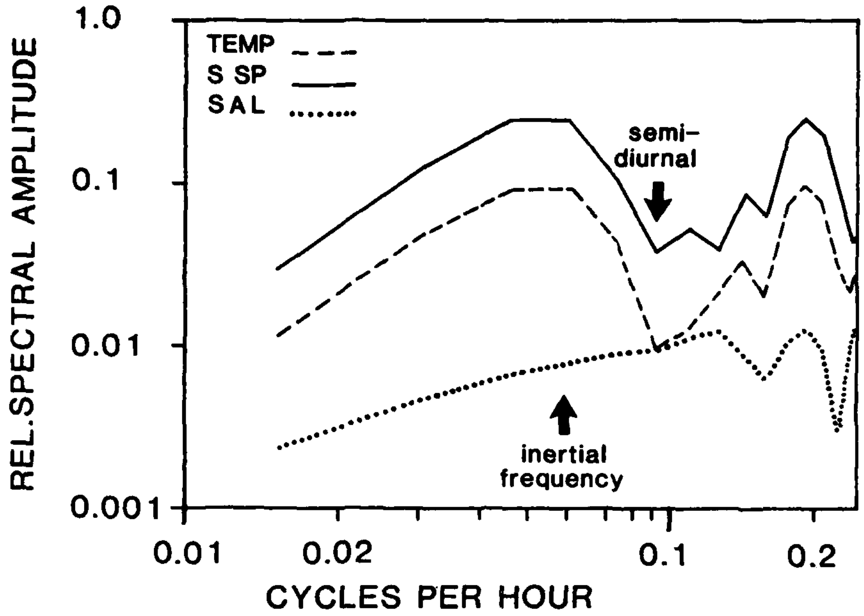

FIG. 6 SPECTRA OF ENVIRONMENTAL PARAMETERS AT 25 m DEPTH

3 FLUCTUATIONS IN ACOUSTIC TRANSMISSION LOSS

Figure 7 shows the contours of measured transmission loss, in 1/3 octave bands, in the frequency/time plane for source and receiver depths of 50 m and 40 m, respectively. The higher frequencies, above 1.6 kHz or so, exhibit far more pronounced fluctuations than the lower frequencies. This may indicate that the environmental phenomena responsible are of physical dimensions that are comparable to the acoustic wavelengths of the higher frequencies. In order to demonstrate this selective frequency effect more clearly, the signals at 200 Hz and 160 Hz were compared. The results are shown in Fig. 8.

The spectra, obtained for the same source/receiver depths as those in Fig. 7, emphasize the difference in the effect of environmental variability. These results suggest that the optimum frequency range is less susceptible to environmental variability than other frequency ranges. A comparison of these spectra with those shown in Fig. 6 reveals a good correlation between the spectra of environmental variability and the higher frequency transmission loss spectrum. The shift of the spectrum towards the semi-diurnal frequency, evident in the transmission loss spectrum, can be attributed to the differences in depths, as already indicated. As a final result, Fig. 9 shows the comparison between measured and predicted transmission losses. The calculations were made using a modified form of the SACLANTCEN Normal-Mode Acoustic Propagation Model (SNAP) [8]. Although some differences in details are evident, agreement between the general features is quite good. Since SNAP was used as a range-independent model, the results suggest that the temporal variability in the sound speed profiles was the dominant one, the spatial variation over the 35 km range apparently being less important. Nevertheless, an unequivocal demonstration of this requires the comparison of these results with those from a range-dependent calculation.

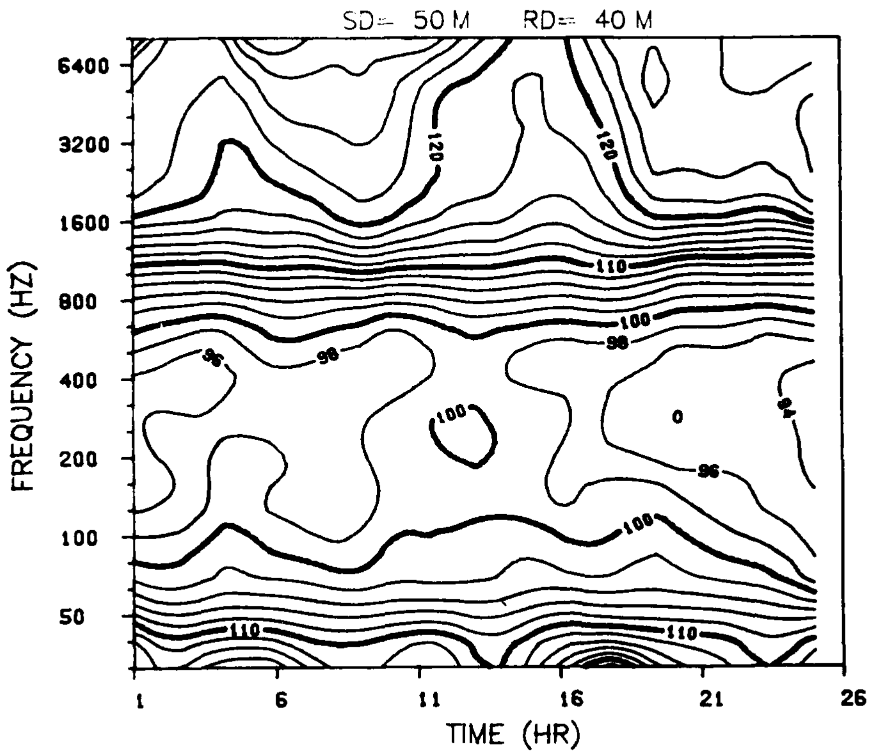

FIG. 7 CONTOURS OF MEASURED TRANSMISSION LOSS FLUCTUATIONS AT A FIXED RANGE (35 km)

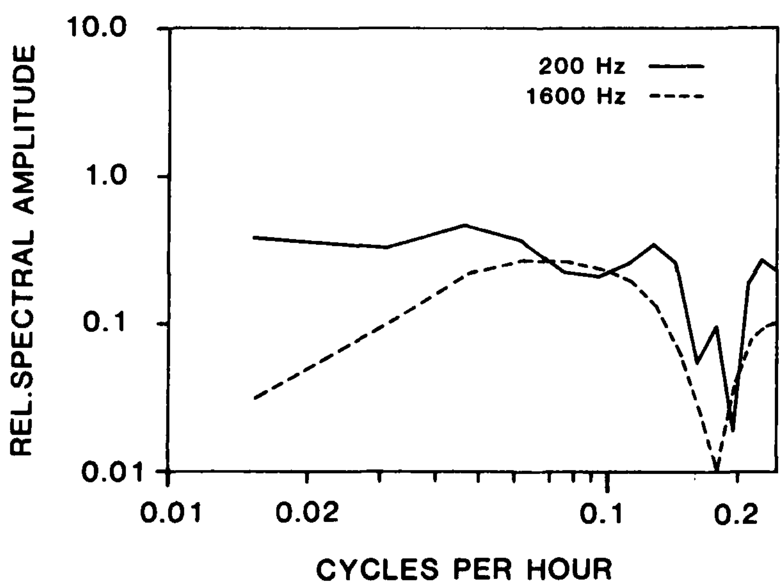

FIG. 8 SPECTRA OF TRANSMISSION LOSS FOR TWO SELECTED FREQUENCIES

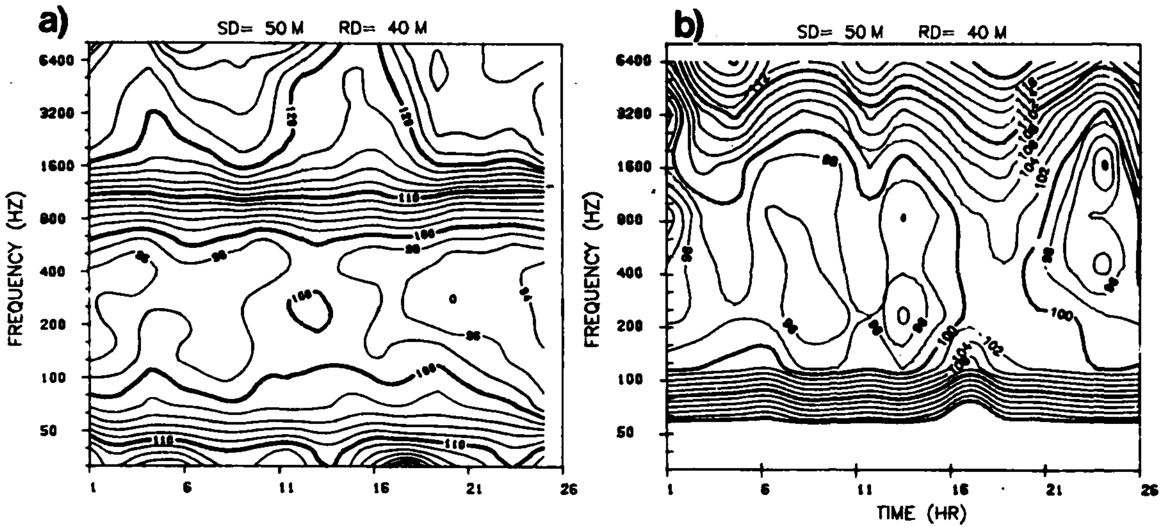

FIG. 9 COMPARISON OF MEASURED AND PREDICTED TRANSMISSION LOSS FLUCTUATIONS AT 35 km (a) MEASURED (b) PREDICTED (SNAP)

CONCLUSIONS

Based on the results of measurements performed in a shallow water area of the Mediterranean, it is concluded that fluctuations in acoustic transmission loss can be correlated with associated variability in the environmental parameters. More particular conclusions include the following:

- Both the environmental parameters and acoustic transmission loss reveal fluctuations at inertial frequencies and semi-diurnal frequencies.
- The inertial effects dominate in the surface layers, whereas the semi-diurnal effects are of greater importance at greater depths, suggesting a meteorological forcing function.
- The fluctuations in the magnitude of acoustic transmission loss are greatest for the higher frequencies (1.6 kHz and above) and least for an optimum frequency range from approximately 100 to 400 Hz.
- Reasonably good agreement has been obtained between measured transmission loss and predictions based on a range-independent normal mode calculation of acoustic propagation (using SNAP) [6].

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KEYWORDS

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BOTTOM BOUNDARY
BOTTOM INTERACTION
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